

Limits on the dark matter particle mass from black hole growth in galaxies

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I review the properties of degenerate fermion balls and investigate the dark matter distribution at galactic centers using NFW, Moore and isothermal density profiles. I show that dark matter becomes degenerate for particles masses of a few keV at distances less than a few parsec from the center of our galaxy. To explain the galactic center black hole of mass of $\sim 3.5 \times 10^6 M_\odot$ and a supermassive black hole of $\sim 3 \times 10^9 M_\odot$ at a redshift of 6.41 in SDSS quasars, the mass of the fermion ball is assumed to be between $3 \times 10^3 M_\odot$ and $3.5 \times 10^6 M_\odot$. This constrains the mass of the dark matter particle between 0.6 keV and 82 keV. The lower limit on the dark matter mass is improved to about 6 keV if exact solutions of Poisson's equation are used in the isothermal power law case. The constrained dark matter particle could be interpreted as a sterile neutrino.

Keywords: Dark matter, sterile neutrinos, galaxies, black hole physics

1. Introduction

There is mounting evidence that most galaxies harbor supermassive black holes (BHs) of masses from $10^{6.5}$ to $10^{9.5} M_\odot$. The typical case is of the Galactic black hole of mass $(3.1 \pm 0.9)10^6 M_\odot$.^{1,2} It has also been established that the mass of the central black hole is tightly correlated with the velocity dispersion σ of its host bulge, where it is found that $M_{BH} \sim \sigma^{4-5}$.³ In spite of the vast and tantalizing work on black hole physics, their genesis and evolution are not well understood. Another outstanding problem in modern astroparticle physics is the particle nature of dark matter (DM). Recently, there has been a renewed interest in sterile neutrinos⁴ as candidates for dark matter as they could explain the baryon asymmetry of the Universe,⁵ the pulsar kicks,⁶ the early growth of black holes⁷⁻⁹ and the reionisation of the Universe.^{10,11} In this short communication, we review the properties fermion balls, i.e. self gravitating systems of sterile neutrinos and study the implications of NFW,¹² Moore¹³ and isothermal density profiles being degenerate near the galactic centers.

2. Fermion balls and dark matter mass limits

We will assume that the DM particles obey a Fermi Dirac distribution function with a non vanishing chemical potential.⁷ Assuming only gravitational interaction, it has been shown that these dark matter particles could condensate at galactic centers forming degenerate fermi balls¹⁴⁻²¹ with a total mass M_F that scales with their size

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R_F as $M_F \sim m_s^{-8} R_F^{-3}$ where m_s is the sterile neutrino mass. Fermions have a maximum mass $M_{0V} \sim m_{pl}^3 m_s^{-2}$ where $m_{pl} = (\hbar c/G)^{1/2}$ is the Planck's mass.

It has been shown that the assumption of a degenerate fermion ball of mass $M_F \sim 3 \times 10^6 M_\odot$ at the center of a dark matter halo of $3 \times 10^{12} M_\odot$ with a density scaling as $1/r^2$ in the outer edge of the halo constrains the fermion mass^{7,9} to

$$m_s \approx 12 \text{ keV}/c^2 \left(\frac{\sigma}{156 \text{ km/s}} \right)^{3/4} \left(\frac{M_{bh}}{3 \times 10^6 M_\odot} \right)^{-1/2} \left(\frac{2}{g_s} \right)^{1/4}, \quad (1)$$

where σ is the velocity dispersion. Using $\sigma = 100 \pm 20 \text{ km/s}$ ³ for the velocity dispersion, and the mass of the black hole of $M_{BH} \sim (2.2 - 4) 10^6 M_\odot$,¹ then we obtain a lower limit on the mass of the DM particle

$$m_s \gtrsim (6 - 12) \text{ keV}/c^2. \quad (2)$$

The above limits lie within the range of sterile neutrino masses obtained from the study of the origin of the high velocities up to 1000 km/s of pulsars.⁶ Moreover, similar limits were also obtained from X-ray background studies.²² Recently, it has been shown that the decay of such a sterile neutrino could help initiate star formation in the early Universe.^{10,11}

The black hole grows exponentially with time from Eddington limited baryonic matter accretion.⁷ However, unless the seed black hole has a high mass of $10^{3-4} M_\odot$, Eddington limited baryonic matter accretion cannot grow the seed black holes to $3 \times 10^9 M_\odot$ black holes in SDSS quasars²³ at $z = 6.41$. We have shown that the Pauli's degeneracy principle helps feed the black hole with dark matter.^{7,9} Stellar seed black holes could be grown to $10^{3-4} M_\odot$ in about 10^{7-8} years. For this model to work, the dark matter particle mass has been constrained to be in the order of 10 keV.⁷ A further growth to $10^{6.5-9.5} M_\odot$ is achieved through Eddington baryonic accretion.

Another constraint on the dark matter particle mass is obtained by studying the NFW, Moore and isothermal density profiles of $\rho \sim r^{-s}$ with s being the power law slope and $s = 1$ for NFW,¹² $s = 1.5$ for Moore¹³ and $s = 2$ for the isothermal profiles. The mass enclosed within a radius r scales as $M_r \sim r^{3-s}$ and the corresponding rotational velocity scales as $v_{rot} \sim r^{1-s/2}$. We then study the conditions under which these density profiles satisfy the Pauli degeneracy condition $m_s v_{rot} \sim \hbar n_s^{1/3}$, where n_s is the sterile neutrino number density. It is found that for all the three density profiles^a dark matter becomes degenerate for particle masses between 0.6 keV and 82 keV.⁸ The lower limit could be improved to about 6 keV if full solutions of Poisson's equation are used.⁷ The mass of the degenerate core is assumed to be between $3 \times 10^3 M_\odot$ and $3.5 \times 10^6 M_\odot$. The black holes grow then by

^aFor NFW profile, the DM particle mass is in the range of $0.6 \text{ keV} \lesssim m_s \lesssim 6 \text{ keV}$. A range of $1 \text{ keV} \lesssim m_s \lesssim 14 \text{ keV}$ is found for Moore profile and finally we obtain a mass range of $2 \text{ keV} \lesssim m_s \lesssim 82 \text{ keV}$ for the isothermal density profile.

consuming the whole mass from degenerate cores and then by Eddington baryonic matter accretion at late stages of their evolution, i.e. at $t \gtrsim 10^{7-8}$ years.

3. Conclusion

Fermionic dark matter of mass of the order of a few keV could help boost the growth of supermassive black holes at galactic centers. Moreover, NFW, Moore and isothermal density profiles become degenerate for particles mass of a few keV at distances of a few parsec from the galactic centers. The detection of an X-ray line at half the sterile neutrino by XMM-Newton and CHANDRA satellites would be the smoking gun for the existence of a such sterile neutrino.

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